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Trends and sustainability criteria of the production and use of liquid biofuels

A. Markevičius *, V. Katinas, E. Perednis, M. Tamašauskienė

Lithuanian Energy Institute Laboratory of Renewable Energy, Breslaujos 3, LT-44403 Kaunas, Lithuania

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ABSTRACT

Environmental impacts associated with the use of fossil fuels, rising prices, potential limitations in supply and concerns about regional and national security are driving the development and use of biomass for bioenergy, biofuels and bioproducts. However, the use of biomass does not automatically imply that its production, conversion and use are sustainable. Conflicts between various ecosystem services (economic production of food, fodder and fuels, biodiversity, social and cultural values, etc.) that are provided by fertile land are increasing as well. Hence, a developed thinking on how to balance between these services is desirable.

There is a significant amount of information available on biofuels and their sustainability. In this paper, different initiatives and sustainability criteria for biofuels are presented and assessed.

35 criteria were found in emerging sustainability assessment frameworks. The majority of 12 criteria were focused on environmental issues, 4 were social and only 1 was economic. Energy balance and greenhouse gas balance were perceived as especially critical, social criteria ranked generally low. Although being perceived as important, food security ranked very low.

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Contents

1. Introduction

There is an increasing awareness that climate change is caused by anthropogenic emissions of greenhouse gases that mainly originate from the use of fossil fuels. In the EU member states as well as in other parts of the world, energy policies are being developed that discriminate fossil fuels and/or promote the use of renewable energy sources.

In January 2008 the Commission presented a directive that aims to further promote the use of renewable energy sources and thereby among other things contribute to climate change mitigation and a sustainable development. The directive establishes a target of a 20% share of renewable energy sources in energy consumption and a 10% target for biofuels in transport by the year 2020. While the potential to deliver larger volumes of biomass from forestry and agriculture for bioenergy production is still great, there is a need to analyze and distribute information about the various characteristics that define sustainable bioenergy production systems. Conflicts between various ecosystem services (economic production of food, fodder and fuels, biodiversity, social and cultural values, etc.) that are provided by fertile land are increasing as well. Hence, a developed thinking on how to balance between these services is desirable.

2. Trends in the production and use of liquid biofuels

The motives to use biofuels elsewhere in the world are often different. Transportation consumes 30% of global energy and is

* Corresponding author. Tel.: +370 37 401845; fax: +370 35 1271.
E-mail address: marke@mail.lei.lt (A. Markevičius).

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responsible for 21% of global annual green house gas (GHG) emissions [1]. The USA is particularly concerned with providing energy security and to use biofuels production to assist rural and agricultural development, to develop new industry and diversification of energy resources. The House of Lords report on the EU strategy on biofuels (2006) reviews and examines EU policy on biofuels in-depth. This report points out that the major motivation for EU policy in this area is:

- Biofuels provide means to decrease GHG emissions from transport.
- They can be grown and used in the country of origin.
- They decrease dependency on oil imports, which can make up a large proportion of the gross domestic product (GDP) of some developing countries.
- They are similar in properties to oil and can therefore be blended with petrol or diesel.
- They can provide a means to improve rural economies such as the introduction of potential new cash crops and the development of infrastructure in rural areas.

2.1. Worldwide use of transport biofuels

Worldwide use of transport ethanol equaled 18.4 Mtoe in 2006, whereas the use was only 9.3 Mtoe in 2000 (see Fig. 1). The main producers of ethanols were Brazil and the USA. Biofuels accounted for 1.5% of the overall road transport fuel demand in 2006. According to forecasts by the International Energy Agency [2], the use of gasoline and diesel for road transport will double in the next 25 years and greenhouse gases will increase commensurably unless preventative actions are taken and/or new car and engine technologies are introduced. Road traffic causes already some 84% of all emissions from the transport sector in the EU. The share of traffic of total energy consumption in the European Community is over 30% and is constantly growing, as are the GHG emissions. This is why the European Commission's White Paper claims that traffic dependency on fossil oil (currently 98%) should be reduced by using alternative fuels such as biofuels.

International Energy Agency predicts [3] that the use of biofuels in transport would rise from 20 Mtoe in 2005 to 92 or 147 Mtoe in 2030 corresponding to 4% or 7% of the world transport fuel demand in the reference scenario or the Alternative Policy scenario, respectively. Second generation biofuels are expected to become commercially viable but still to make only a small contribution to the total supply of biofuels by 2030. Most of the growth is expected to come from the United States, Europe, China and Brazil. Within the recent few years several countries, including the United States, China and the European Union, have announced aggressive policies for encouraging the production and use of biofuels. Some countries, in particular the EU, have started to reconsider their ambitious biofuel policies due to the concern of sustainability issues. The European Commission and Parliament has set a 10% binding minimum target for biofuels or renewable energy in transport to be achieved by each Member State by 2020. A 10% replacement of EU's diesel demand by conventional Fatty Acid Methyl Esters (FAME) biodiesel would account for about 19% of world vegetable oil production in 2020. A 10% replacement of EU gasoline by bioethanol would use about 2.5% of the world's cereals production. Organization for Economic Corporation and Development (OECD) expects the average world agricultural yield improvement to remain at about 1% per annum, which is less than half of their forecast of the world demand increase (2.3% per annum). So if the EU target would be covered by increased use of crop-based biofuels, more land will be planted with crops and increased demand of biofuels will cause land-use changes.

Alternative options are the production of so-called 2nd generation biofuels from lignocellulosic resources (like wood, straw, and reed canary grass) and/or the import of biofuels. Optional routes include the use of animal based waste grease or tallow and used cooking oils for biodiesel production and organic wastes from the food sector for bioethanol production. These routes are applicable in case sufficient amounts of raw materials of acceptable quality can be collected and delivered to processing plants at reasonable cost. Hydrogenation of oils and fats is a new process that has entered the market. The economics of current biofuel technologies are heavily dependent on feedstock costs. As a result there is considerable pressure on the cheapest feedstocks. Therefore there are a number of technologies being developed to allow the production of biofuels from lignocellulosic and other low-cost raw materials. The impetus behind this development is twofold: new technologies allow the use of wastes, residues, and feedstocks that currently have little value or use and they enable more sustainable or more efficient land-use. These new technologies have typically high investment costs and cost-effectiveness is sought by large-scale plants and integrating the biofuels production to existing chemical or forest plants in addition to utilising low-cost feedstocks. There are already demonstration plants in operation and more demonstration plants are being planned and/or under construction. For example, the forest company UPM Kymmene has activities in developing ethanol production from waste streams and Fisker Trop (FT) diesel production from woody biomass [6]. The forest company Stora Enso, and Neste Oil have founded a joint venture NSE Biofuels and they are developing their own FT diesel process [7]. In addition, share of diesel fuel is projected to increase in Europe.

Biodiesel has been produced on an industrial scale in the European Union since 1992. The production has grown significantly over the past 10 years. There has been an average increase of 36% per annum between 1992 and 2007 [8]. Today, there are approximately 120 plants in the EU producing more than 6 million tons of biodiesel annually (Fig. 2). These plants are mainly located

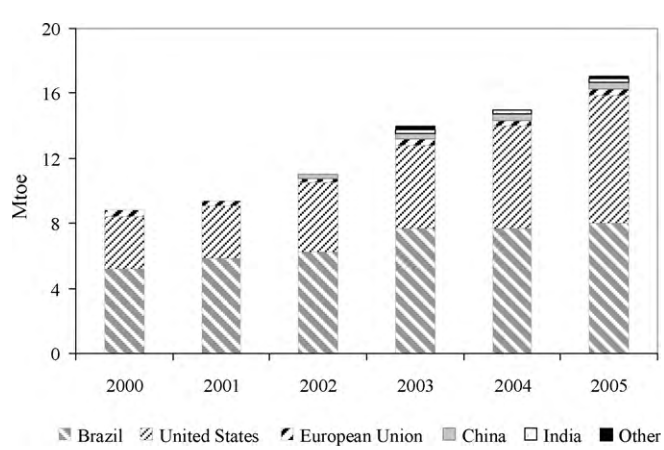


Fig. 1. Global bioethanol production 2000–2005 [5].

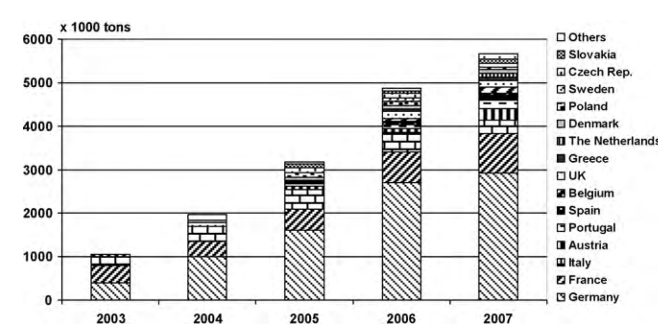


Fig. 2. Biodiesel production in the EU between 2003 and 2007 [9].

in Germany, Italy, Austria, France and Sweden. More than half of the biodiesel in the EU is today produced in Germany.

Biodiesel feedstock markets worldwide are in a transition from increasingly expensive first generation feedstocks, such as soy, rapeseed, and palm oil to alternative, lower cost, non-food feedstocks.

Biodiesel production from non-food feedstocks is gaining attraction around the world. For example, China recently set aside an area the size of England to produce jatropha and other non-food plants for biodiesel. India has up to 60 million hectares of non-arable land available to produce jatropha and intends to replace 20% of diesel fuels with jatropha-based biodiesel. Also in South America and Africa, there are significant programs underway dedicated to producing non-food crops such as jatropha and castor oil for biodiesel [9].

The suitability of fats and plant oils for diesel use is due to their molecular structure and high energy content. However, fats or plant oils as such are not suitable for high-speed diesel engines (light- and heavy-duty vehicles), and further processing is required. The traditional transesterification process with methanol, using sodium or potassium hydroxide as a catalyst, results in traditional biodiesel, FAME and glycerol as a co-product. Another option is to use a hydrotreatment process (e.g. the NExBTL process) for the production of high-quality paraffinic biodiesel.

Benefits of FAME esters are good cetane numbers, low sulfur content, no aromatics, and good lubricity. However, the FAME biodiesel has also drawbacks, e.g. high viscosity, poor cold properties, problematic distillation characteristics (dilution of engine oil), difficult impurities (triglycerides, glycerol and alcohols), problems with materials, and poor storage stability [10]. Due to these problems the current European EN 590 (2004) specification for diesel fuel limits the maximum concentration of FAME in diesel to 5% (7 volume − % anticipated in the future). The European standard EN 14214:2003 sets requirements for the quality of FAME used for automotive fuels.

3. Key indicators and sustainability criteria against which these can be assessed for biofuels systems

Sustainability, that is environmental, economic, and social implications of biomass-based products, such as biofuels, varies significantly between the products and depends on many factors. Sustainability assessment is an extremely complicated and a challenging task due to the lack of a unique, objective, and commonly agreed methodology. Consequently, the definitions of system boundary, reference scenario, and other assumptions will have a significant impact on the results and are subject to significant uncertainties and sensitivities.

Key indicators and sustainability criteria against which these can be assessed for biofuels systems are presented in Table 1.

For example, inclusion or exclusion of system impacts caused by market mechanisms due to the biofuel production on land-use or the energy system may have more impact on the greenhouse gas balances than the other life-cycle phases together. In addition, other environmental impacts than climate change, as well as social and economic impacts are typically very case and site specific and are caused in life-cycle phases that may not be of significant importance, when assessing only greenhouse gas emissions. Besides greenhouse gases causing climate change, the emissions from the lifecycles of biomass-based fuel chains include other compounds regarded as hazardous to human health and the environment. These emissions may be released to the air, soil, or water, thus causing various impacts, including acidification, trophospheric ozone formulation, eutrophication, ecotoxicity and human toxicity. The emissions and different processes during the life cycle of the biomass-based products may also lower the quality of the air, soil and water. Additionally, the cultivation and harvesting of biomass have an impact on biodiversity. Furthermore, social and economic implications in such areas as workers rights, child labor, women's equity, employment, and local economy are associated with the use of biomass. These impacts can vary significantly due to various raw materials, production conditions, end-use products, and regions.

Many of these impacts, other than climate change, are more relevant on the local than on the global level. Global biomass and land area for biomass production are limited resources, in particular concerning the technically and economically attractive ones.

Consequently, the boosting production of biofuels may increase the competition for raw materials and land between various end-use purposes of biomass, such as for food and feed, materials, chemicals, fuel use, and electricity and/or heat production. Examples of these kinds of indirect impacts of increasing biofuel production are rain forest and permanent grassland clearings for palm oil and soy cultivation that have occurred in Southeast Asia and South America. The implications of such impacts may be very negative, examples being remarkable losses in carbon pools and biodiversity in very diverse and sensitive regions like tropical rain forests. Famine and poverty, due to increased food prices may furthermore be the indirect results of increased production and use of biomass for energy purposes.

Table 1
Key indicators for biofuels systems.

Key indicator	Criteria against which it is assessed
Land-use change	Is the crop planted on arable, marginal, degraded or other uncultivated land? Is the crop planted on high conservation value (HCV) land? Will food crops be displaced to HCV land? Will deforestation of land prone to degradation take place?
Biodiversity management	As above but with consideration of the ecosystem. Will habitat fragmentation occur? Will ecosystem corridors be maintained? Will the ecosystem services change? Are there any-key indicators: species in danger?
Water use	Is water use an important factor in local agriculture? Are crops typically rain fed or irrigated? If the latter is important, does the crop have higher or lower water requirements than the current land-use? Will irrigation increase yields and therefore be tempting to farmers trying to maximize income? Will this stress local water supply? Does cultivation of the crop result in higher water losses from the soil? Is the crop planted in a key water catchment area and will its water demand influence the catchment area?
Water pollution	Will ground water or surface water pollution increase as a result of biofuel production?
Soil health	Will the land-use change result in impact on soil health such as erosion or loss of soil organic matter? Will the land-use change result in increased soil stability? Or addition of nutrients or organic matter to the soil? Will the planting of biofuels crops result in intensification of agriculture; with greater inputs of agrochemicals and irrigation?
Effect on food crops	Is a food crop replaced or displaced? Does the use of the crop as a biofuel result in impacts on demand for other food crops?
Air emissions	Are there any additional pollen emissions from cultivation? Is the land burnt to clear for cultivation for subsequent planting? What emissions changes result from use of the biofuel?
GHG emissions	Are there significant GHG emissions savings (including the effect of any direct or indirect land-use change) compared to the fossil fuels they replace?

Consequently, the selection of the approach suitable for the comprehensive assessment of sustainability is a very challenging task.

In order to ensure sustainable production of biomass-based products and biofuels, several initiatives and certification systems on sustainability criteria for biomass and/or biofuels have been proposed or are being prepared by various organisations, institutions, and countries. Work on sustainability criteria of biomass has also been started by the European standardisation organisation CEN. These initiatives vary from each other, e.g. depending on the scope of the application, the validity, the extent, issues considered for environmental, social, and economic aspects, and on conditions set for fulfilling the sustainability criteria.

In order to operationalize sustainability assessments of biomass systems, it is crucial to identify critical criteria, but keep them at a manageable level. The selection of these criteria can vary depending on individual's expertise, geographical region, and attribute on spatial scale. No clear consensus has yet emerged as to what experts consider critical indicators of sustainability. Objectives of paper [12] were to analyze how experts score sustainability criteria and to identify levels of agreement and uncertainty. Input on sustainability criteria for bioenergy systems was based on ratings and rankings from 46 international experts from academia, business and NGOs.

Through a literature review, there were identified 35 sustainability criteria which are regularly discussed in the context of bioenergy use. Sources for criteria identification included Cramer et al. [13], van Dam et al. [14], Fritsche et al. [15], Jürgens and Best [16], Lewandowski and Faaji [17], Modi et al. [18], Reijnders [19], Five Winds International [20], Smeets et al. [21], the Sustainable Bioenergy Wiki [22] of the Roundtable on Sustainable Biofuels (RSB) Lausanne, Upreti [23], and the World Energy Council [24].

Criteria were grouped into the broad categories of social (15 criteria), economic (4 criteria) and environmental (16 criteria). Participants were asked to score each of these 35 sustainability criteria on four attributes including relevance, practicality, reliability, and importance using the following definitions (Table 2).

Table 2
Social, economic and environmental criteria.

Crit. no.	Criterion name	Criterion explanation
Social criterion		
1	Compliance with laws	Complying with all applicable laws and internal regulations like certification principles, countering bribery
2	Food security	Enough land locally available for food production including agricultural set aside land, preference of marginal sites for energy crops
3	Land availability for other human activities than food production	Enough land locally available for housing, energy (e.g. firewood), recreation, and other resource supply
4	Participation	Inclusion of stakeholders in decision making; facilitation of self determination of stakeholders
5	Cultural acceptability	Consideration of spiritual values, handling of local knowledge
6	Social cohesion	Migration and resettlement, wealth distribution, fair wages, intergenerational equity, charity
7	Respect for human rights	Health services, liberty rights, security, education
8	Working conditions of workers	Worker health, work hours, safety, liability regulations, exclusion of child labor
9	Respecting minorities	Recognition of indigenous peoples' rights, gender issues
10	Standard of living	Public service support, access to energy services (e.g. electricity lifeline tariffs)
11	Property rights and rights of use	Land and resource tenure, dependencies on foreign sources (e.g. financial investments, knowledge) fair and equal division of proceeds, customary rights
12	Planning	Stating clear objectives, a management plan is written, implemented, and updated as necessary
13	Monitoring of criteria performance	Monitoring systems in place for all criteria (e.g. leakage or additionality in GHG accounting)
14	Visual impacts	Visual effects of construction and feedstocks on landscape
15	Noise impacts	Noise from production, transportation and conversion processes
Economic criterion		
16	Employment generation	Number jobs created, quality of jobs created
17	Microeconomic sustainability	Cost-efficiency incl. startup costs, internal rate of return, net present value, payback period
18	Macroeconomic sustainability	Trade balances, foreign investments, financial flows across project boundary, changes in overall productivity, 'economic development'
19	Economic stability	Project lifetime, degree to which applied technology and operational aspects are proven, flexibility to changes in demand and supply, product diversification
Environmental criterion		
20	Adaptation capacity to environmental hazards and climate change	Diversification of feedstocks, available knowledge on site demand of feedstocks
21	Energy balance	Conversion efficiencies, energy return on investment, energy return per hectare
22	Natural resource efficiency	Efficient use of resources at all stages of the system
23	Species protection	Protection of rare, threatened, or endangered species
24	Ecosystems protection	Safeguarding protected, threatened, representative, or other valuable ecosystems (e.g. forests), protecting internal energy fluxes/metabolism
25	Ecosystems connectivity	Preventing land fragmentation, e.g. presence of wildlife corridors, etc.
26	Crop diversity	E.g. impacts and risks associated with monocultures like its impacts on landscape and wildlife, and its susceptability to catastrophic failure
27	Exotic species applications	
28	Use of genetically modified organisms	Appliance with law, risk to other land uses
29	Use of chemicals, pest control, and fertilizer	Insecticides, herbicides, chemicals in the conversion process, impacts on surrounding environment
30	Soil protection	Impacts on soil fertility like. Changes in nutrient cycling, rooting depth, organic matter, water holding capacity, erosion
31	Land-use change	Impacts of land conversion on energy fluxes, radiation balance, roughness of land cover, biochemical fluxes, hydrological cycles which eventually affect ecological balances
32	Water management	Surface and groundwater impacts, riparian buffers, irrigation and cooling cycles and waste water management
33	Waste management	Disposal of ashes, sewage, hazardous/contaminated solid and liquid material
34	Greenhouse gas balance	GHG-balance of system covering CO_2, CH_4, O_3, NO_2, H_2O
35	Potentially hazardous atmospheric emissions other than greenhouse gases	Emissions of SO_x, CO, NO_x, and particulates

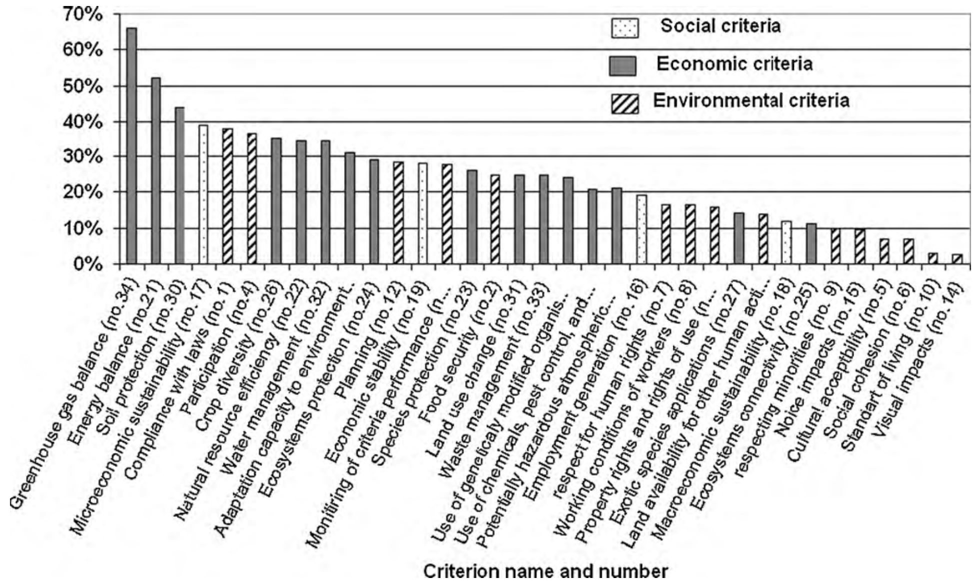


Fig. 3. Ranking of social, economic and environmental criteria.

4. Respondents scoring criteria as critical

Energy balance and greenhouse gas balance were perceived as especially critical (Fig. 3). Social criteria and locally applied ones ranked generally low in all four attributes. Ten of the twelve most important criteria based on average scores also lead the list of the most critical criteria for inclusion. The majority of these 12 criteria were focused on environmental issues, 4 were social and only 1 was economic. Although being perceived as important, food security ranked very low in both practicality and reliability. Scale of operation and profession of experts explained most of the ranking differences between experts rather than regions. Low ranking criteria, especially in the attribute importance, were characterized by a low consensus suggesting the need for further debate regarding their inclusion in sustainability assessments.

5. Life cycle assessment (LCA) as a tool for sustainability assessment

The life cycle approach is one of EU main environment impact assessment criteria (ISO 14040, 1997; ISO 14041, 1998; ISO 14042, 2000; ISO 14043, 2000; ISO/TR 14049, 2000). The sustainability of a fuel product depends on its environmental, economic and social impacts throughout the products entire life cycle. The complete life cycle of the fuel product includes everything from raw material production and extraction, processing, transportation, manufacturing, storage, distribution and use. A fuel chain and its life cycle stages cause various harmful impacts on the environment. In addition, the life cycle stages can have harmful effects or benefits of different economic and social dimensions. For this reason, the total management of complete fuel chains (cradle-to-grave) from different perspectives is of crucial importance in order to achieve sustainable fuel products and systems in our society. For this purpose LCA appears to be a valuable tool and its use for the assessment of the sustainability of not only fuel products, but also of other commodities has increased dramatically in recent years.

In the application of LCA on a biofuel product system, the functional unit offers a reference unit, for which the inventory and impact assessment results will be presented, making it possible to compare the results with the results of reference products. This reference product is typically a fossil fuel or an alternative biofuel product. In the context of biofuels, the system boundary can be determined as "well to tank", "tank to wheel" or "well to wheel".

Inventory data and environmental interventions representing a "well to wheel" perspective, are the core elements of a LCA. However, the inventory data are usually not sufficient for making a decision regarding which fuel alternative is the best from the viewpoint of environmental aspects. For example, it is difficult to give an answer to the question, whether emissions of sulfur dioxide (SO_2) should be regarded as more severe than emissions of nitrogen oxides (NO_x). In comparative studies, such as biofuel comparisons typically are, it may be found that biofuel A is better than biofuel B with regard to some emissions, but poorer with regard to others. In such cases, the impact assessment phase should be included. Life cycle impact assessment (LCIA) helps to interpret the results of the inventory from the environmental impact point of view. However, a life cycle study does not always need to use impact assessment. In some cases conclusions can be drawn and judgements and valuations are possible just on the basis of the results of the inventory phase.

The economic and social dimensions of sustainability have so far not been included in LCA. However, these dimensions throughout an entire life cycle of a product can be assessed with the help of tools called life cycle costing (LCC) and life cycle social assessment (LCSA). In addition, environmental extended input–output modelling offers possibilities to combine all three dimensions of product systems being assessed [25].

When assessing environmental impacts of any kind of a system the most critical issue to be responded to is: *What is compared with what?*

In general it can be concluded that measuring the sustainability of biofuels and biomass is difficult. There are three sustainability aspects – environmental, economic and social – of which each consists of numerous sub-categories. Often the implications of the aspects are contradictory. This makes the setting up of strict sustainability criteria for biomass or biofuels a very challenging task. This is reflected in the number and scope of existing initiatives and certification systems. Many criteria (such as the GHG-balance and land-use change) cannot be covered within the existing initiatives and certification systems [26]. Therefore, further development of the criteria to ensure sustainable production of biomass and biofuels is needed urgently.

Therefore a better international coordination between initiatives is required to improve the coherence and efficiency in further development of biomass certification systems [26]. Currently, the Dutch and the UK's initiatives are the most comprehensive ones. From the consumers point of view, it is almost impossible to know different initiatives and their real impact on sustainability.

6. Conclusions

The EU directive establishes a target of a 20% share of renewable energy sources in energy consumption and a 10% target for biofuels in transport by the year 2020. So if the EU target would be covered by increased use of crop-based biofuels, more land will be planted with crops and increased demand of biofuels will cause land-use changes.

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